IMPLEMENTING STUDENT CREATED ATOMIC SCALE DEPICTIONS ACROSS MULTIPLE UNITS TO IMPROVE UNDERSTANDING OF MOLECULAR INTERACTIONS IN HIGH SCHOOL CHEMISTRY

by

Christopher S. Jones

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I would like to thank my students for their willingness to try something new and to share what they believed about the treatment, and my family for allowing me the hours spent away from their priorities while I pursued this goal.

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ABSTRACT

One of the most difficult aspects of studying chemistry is that one must imagine the atoms and molecules interacting to understand many of the concepts. Students were tasked with drawing molecular processes in a series of frames to demonstrate atomic interaction and provide context to aid retention. Exam scores for the units which included this task were compared to previous two years' results. The exams consisted of the same questions for all three years. Students were surveyed about the perceived instructional benefit and enjoyment of the activities and how often they included drawings in their notes. Surveys were analyzed for changes in frequency of drawing in their homework, affect for the treatment, and perceived effect of the task over the course of the treatment. Exam scores for the treatment units were not significantly higher or lower than in previous years. One aspect that was remarkable was the discrepancy between the students' belief in the efficacy of the intervention despite their lack of affect for it. The students generally believed the curriculum was more effective than it was. They also tended to express less satisfaction with the drawing treatment as the year progressed. Interviews were conducted with students who voluntarily expressed both positive and negative experiences, as well as others who were selected randomly.

INTRODUCTION AND BACKGROUND

I teach chemistry at Foothill High School in Pleasanton, California. Over twenty years at the same school site, I have also taught biology, physics, zoology and most recently Advanced Placement (AP) environmental science. School Enrollment at the time of the study was approximately 2275 students of diverse ethnic groups and relatively high-income levels from a national perspective. However, for the San Francisco bay area, it is closer to the middle of income and diversity curves. The district has another comprehensive high school of similar size and a continuation school with between 100 and 150 students serving a community of approximately 82,000 people. The median family income is $132,000. While that may seem exceptionally high, the median house price is $840,000, with a median mortgage payment of $3,200 and monthly rent median of $1,950. Sales tax here is 9.5% (retrieved from http://www.bayareacensus.ca.gov/cities/Pleasanton.htm, May 19,2019). Our department usually teaches 65 sections of science a year, with multiple sections of all AP courses and zero offerings that do not meet the University of California guidelines for lab sciences. Chemistry classes at Foothill are capped at 32 students, and my study cohort included 110 students in four classes. Of these, 72% were sophomores, 19% freshmen, 7% juniors and 2% seniors. There were 9 English Language Learners in my four chemistry classes and 17 students with individualized education plans (IEP). Approximately 60% of graduating seniors go on to a four-year institution, and 20% to a junior college.

The students at Foothill are well behaved, respectful and supportive of one another. Disciplinary issues are both scarce and relatively minor. This is a school ranging from truly wealthy students whose families own professional sports teams to the five to seven percent who qualify as socioeconomically disadvantaged. It is racially diverse, but the school culture has very little ethnic partitioning – groupings of students are interest based – with white girls in Chinese yo-yo club and African American boys dancing Bangra. Certificated staff are compensated near the top of the regional range. No one in my department is teaching a course they are not demonstrably well qualified to teach under California standards. While there is never a situation where school staff believe they have enough financial support, resource availability is certainly sufficient at Foothill High.

I love teaching these kids about aspects of the physical world that they cannot see. One of the things that makes chemistry difficult for students is the same thing that makes it so rewarding to teach – no one will ever see the objects we are teaching them about throughout the year - they are simply too small. The topics I teach the students over the year are often truly new ideas to them. The moments we all cherish when you can see the child's face change with the light of comprehension happens more often than in other classes. Students can prove ideas and concepts through inference and hands-on laboratory experiences, but visualization of molecules will always be based in some sort of model that is fundamentally an approximation. Developing our students modelling ability is undoubtedly important. The ability to imagine forces and energies that cannot be seen is essential in any later science pursuits. Even for those who will never take another science course in their lives, models are used to scaffold information in subjects from economics to automobile repair.

The creation of a model requires significantly more attention to detail and processing than simply looking at a rendering or holding a three-dimensional representation someone else created. Cooper, Stieff and DeSutter (2017) argue that “students who do not sketch develop less complex mental models” (p.916) yet science education has drifted toward less and less process and more toward product. Consider a typical chemistry students’ homework. Laptops and internet based classroom management systems such as Google Classroom make it easy for the student to copy images into their work, and the resulting document looks better and may be more complete than if they did it by hand with pencil and paper. The product looks more professional, but I believe we trade the learning opportunity that comes from the attention to detail drawing requires. When we allow this, we value the product over the process. With the explosion of new scientific knowledge through the twentieth century, the shift away from assessing process that was common 100 years ago toward the recitation of facts that is so prevalent today was all the more likely. It is easier and less expensive to assess content knowledge than powerful thinking. Since science education is so much more expensive than in any other topic, it is often the first place accountants look when it is time to cut spending (Lerner, 2017). This is certainly not the only force pushing schools away from a more constructivist philosophy, but in our current era of high stakes multiple choice assessment, I would argue it is the greatest of the forces working against learning scientific process and instead favoring fact retention. I have high hope for the transformative potential of the NGSS, but there is strong resistance to change.

Traditional science education has been grounded in developing strong observational skills. I believe there is value in both the process of creating a drawing of submicroscopic scale and the ultimate product of the hands-on effort. Cooper, Stieff and DeSutter (2017) describe a typical chemistry class in both high school and college students are “tasked with memorizing the basic procedures for sketching chemical representations, yet they are not held accountable for understanding the associated explanatory model.” (p.905) This was foundational in forming my research questions. Can I create an activity that will enhance the students ability to understand and retain these fundamental models of molecular interactions? For example, students were required to draw the phase change sequence of water molecules as they transition from a rigid, intermolecular force constrained snow flake to a drop of liquid, through to a few molecules of vapor as heat is added to the system. In order to do so, they needed to think about and show the result of the many forces that make these phases behave as they do. Would taking the time to draw it out as a sequence of events between the molecules as heat is added provide perspective and context that would help them on exams?

Cooper et al. and Ainsworth’s papers consistently warn us as educators to not rely on drawing as a panacea (Ainsworth et al., 2011, Cooper et al., 2017). However, even if the student were to get nothing out of their efforts to create such a drawing, I also firmly believe that studying our own work is more effective than studying someone else’s. This is why I chose to do my capstone work on measuring the effectiveness of drawing in a chemistry classroom. Specifically, I intend to answer three questions. First, does adding drawings of molecular processes make a demonstrable impact on high school student’s degree of success? Second, do the students believe the drawing activities implemented were worthwhile? Last, can the students apply the concepts they modelled in the drawings to novel situations in assessments?

CONCEPTUAL FRAMEWORK

The implementation of the Next Generation Science Standards (NGSS) throughout the nation focuses on changing several aspects of how we educate American children. Appendix A of the NGSS guiding document describes the seven major conceptual shifts that are to be implemented throughout – all based on the National Research Council's 2012 Framework for K-12 Science Education (2013, NGSS Appendix A). My work is intended to test the effectiveness of a novel way to address two aspects of the first physical science standard, matter and its interactions through one of the cross cutting concepts (CCC4: Systems and System Models). Specifically, PS1a – How do particles combine to form the variety of matter one observes? and PS1b – How do substances combine or change to make new substances? How does one characterize and explain these reactions and make predictions about them? (NRC, 2012 Framework for K-12 science education, pages 106 - 109). Specifically, can using drawn system models in the form of a comic strip; a) describe and explain inter-atomic and inter-molecular level interactions and b) improve development of the ability to predict the behavior of those dynamic systems?

Using drawing in the sciences is nothing new. From Aristotle on, explanations were traditionally accompanied by the authors drawings. However, over the past twenty years of my experience teaching high school I have seen the development and assessment of science learning shift away from this skill. This may have been driven by the increased value of high stakes state and national tests. Their tendency to be primarily in multiple choice format is often decried by my colleagues. But I believe it has deep roots in our adaptation to the technologies available to us. Lerner (2007), in an essay praising early teaching techniques of 1920's biologist Agassiz, describes modern Sophomore zoology students at MIT complaining that they were asked to draw zebra fish embryos when they could easily take digital photographs and create a slide presentation. Agassiz is quoted as saying "There is no better set of eyes than the pencil." (p. 388) In discussions with professors at Saint Mary's College of California (R.Wensley, personal communication September 15, 2017) and Montana State University (Lageson, personal communication June 25, 2017), both men talked about how they believed that foregoing the physical act of drawing for digital photographs prevented students from seeing the details that the professors believe are necessary. Digital photographs are wonderful, and they provide a product that is far superior to my drawings and certainly better in every way than what all but the most talented could draw. However, I believe there is value in the process of drawing that is far greater than the resultant product of the effort.

The development of a broad range of representational skills is essential in becoming proficient in the sciences. Ainsworth, Prain, and Tytler (2011) suggest five reasons that drawing should be considered as important a skill in science as writing, reading and speaking. Enhanced engagement with the subject and as a means of communicating ideas are listed as simple but vital. Three of their reasons are especially relevant to my focus. Learning to represent evidence in graphical form is something that all teachers would agree is difficult for students at many levels. For example, drawing different aspects of the same phenomena to better understand the whole – the authors point to representing sound waves in three aspects; as wave diagrams, sequential compaction and rarefication of air molecules, and pressure differences. Combining all three provide a better understanding of what we call the truth. Developing the ability to reason is the fourth - as students compare their drawings to their teachers or peer's representations, they reason out refinements of their own in similar and complimentary ways to that of a verbal discussion or argument. Last, using drawing to organize thought and integrate new information such as when students are asked to draw out a scene from a story are classically constructive techniques that often lead to the desire to expand and predict what would happen next. Fundamentally, they support drawing as essential both in student's expression and their development of understanding in the sciences.

Drawing may be important in tying together what students see in their science text books as well. Ainsworth (2006) writes about the connection between Multiple External Representations (MERs) and their expansive use in modern science textbooks but cites conflicting results that both support and refute their effectiveness in improving student outcomes. There is strong support in the literature for students constructing their own external representations as this skips the need to figure out what the provided graphic is intended for, a problem cited by multiple other researchers.

There is also contrasting evidence regarding the inclusion of drawing as an effective learning method for all students. Results from Zhang and Linn (2011) found mixed results in extensive classroom studies which included more than a hundred middle school students. While they saw a solid relative improvement for students who started the unit with relatively low formative assessment scores, they saw less value for students with high pre-test scores. Their work shows an excellent model of thoroughness and proper data analysis, but the findings from these middle school students may not translate to the high school cohort my study examined. Also, their work focused on one unit over a three-day period, and all drawings were based on interactions with a computer animation. I intend to implement drawing as a skill the students hone throughout the school year, without any interactive computer models. Lastly, Zhang and Linn hypothesized that the "careful articulation of the reaction contributes to the effect of drawing" (p.1196) and that they planned to investigate the impact of peer discussion as students plan, structure, and edit their drawings. The team seem to have published only one other paper, and it does not address this. Regardless, it seems to be excellent quality work that will be of great help in the design and implementation of my study.

Gobert and Clement (1999) investigated the effectiveness of student generated diagrams against written summaries and a control group of students who simply read a passage describing plate tectonics. Results were mixed between the diagram and text summary groups, with the diagram group performing better on the summative tests higher order questions while the text summary group outperformed the diagram group on the lower level (vocabulary recall) summative questions. Fundamentally this suggests to me that good practice might be to have students produce both diagrams and a text summary. The study was conducted with ten to twelve-year old students, and extensive statistical analysis is provided. Overall the statistics seem over done for such a small sample (n= 58) and the variation in scores seemed too large for much inference to me. Conclusions were drawn, but the statistics seem worthy of closer inspection.

Chittleborough and Treagust (2007) worked with three students in a non-majors chemistry course and conducted a case study of how the students individually went about creating models. The authors argued that how we construct models is personal and thus case studies of individuals is the best means of assessing instruction in modeling. They used a model complexity scheme with three levels and assessed the students' progression over the course of an academic year. The conclusion drawn from the case study was that the process of modeling needs to be taught directly by the instructor and not simply relied upon as a means to convey information.

Cooper, Stieff and DeSutter (2017) wrote the most comprehensive and targeted paper I found relating to how drawing models in chemistry can be applied. In developing a new curriculum, they describe the unique aspects of the modelling in chemistry being a representation of the truly invisible – differentiating it from the visualizations important in other fields such as geology where practicality prevents the student from seeing the underlying rock that underlies what we see on the surface of the earth. They argue that simply increasing the amount or frequency of students drawing is insufficient, and that connecting sketching to the reasoning required to develop models is key. Multiple examples of conceptual development and assessment are discussed, from the solvation of ionic compounds to the energetics of phase change connection to intermolecular forces. They describe a curriculum that uses three types of sketches; 1) Predictive sketches using their prior knowledge, 2) observational representations from lab activities and inferences from their conceptual lessons, and 3) predictive work that tasks students with applying what they have done to new situations. Predictive drawing intentionally force students to revise their model and make guesses based on what they have done. The authors point out that differentiating the impact of student drawing activities from those made by either the teacher or some combination of multiple external representations not generated by the students themselves is problematic. Differentiating between the impact of sketching and dynamic visualizations through other means has failed to show large impacts, and the authors call for research into both the scaffolding impacts of drawing and its value as an assessment tool.

Stieff and Uttal (2015) emphasize that any improvements in a student's ability to think spatially can have broad benefits across a variety of STEM disciplines. There is correlation between both the spatial abilities of both professionals working in scientific or technological fields versus professionals working outside of those areas. These same groups also differ in their spatial reasoning abilities, with higher performance noted for those participating in science courses within a specific curricular window. However, their work cites multiple long-term assessments showing that if the efforts to emphasize spatial thinking are stopped, the skills are not retained beyond past six months. They note that assessing impacts of any focused skill-based program on student outcomes is exceptionally difficult and often inconclusive. This is attributed to the wide range of assessment throughout the curriculum, the impact of affect, and how the participating researchers define the term "knowledge". All these factors are likely contributing to the vagaries of what comprises academic success.

Quillon and Thomas (2014) wrote a comprehensive framework for how to use drawing to promote and develop models in biology curricula. The authors created a matrix relating formative and summative goals from the perspective of what the instructor wishes to accomplish, as well as to abstract and representational drawings that instructors would ask the students to create. It has great potential as a means of developing my implementation strategy and as a basis for a rubric. Specific models and strategies for improving student affect, visual literacy, and model based reasoning are provided based on the instructors planned task are provided. Some interventions for improving student affect were very similar to what Roam (2013) suggests, including establishing the explicit definitions of symbols used, and the modelling advice emphasized the importance of revision and repeated iteration. Although the examples are for biology concepts, the modeling processes described are universal across all science disciplines and includes solutions for common problems encountered when implementing new drawing lessons or assessments. The greatest impact this work has had on my plans relates to the concept of variation, where instructors must allow for variability in student generated models. The example was for chromosome sorting in meiosis. Emphasizing student improvement of their understanding and retention of the process, the authors pointed out that providing intermediate images in a sequence is sometimes beneficial. It prompted me to think of a plan to scaffold molecule formation and other small molecule scale processes as a comic strip where the student would be provided a drawing in the first comic frame and a written description of the scene in the last frame.

Last is a business focused book, *The back of the Napkin* by Dan Roam. This book was referenced in a few papers, and will primarily be useful in preparing the instruction of how to draw what the students want to show. There is an excellent and insightful explanation of the process the author calls visual thinking. Two specific examples I plan to use early on with my students to help them develop representational skill are the difference between looking at something and seeing it. Student can walk themselves through "drawing with detail" by having students conduct a self-assessment on whether the six components of what we see are present. Roam defines "looking" as collecting raw visual information, while seeing implies deciding what is important. The various steps of visual thinking include: 1) what they want to show, 2) how many objects should be presented, 3) the object's position in space (where), 4) position or positions in time (when), and 5) representing the process that occurs (how). Lastly, Roam (2013) would task students with describing the "why". However, for science students I will present it as "How come?" to prompt a written description of what rule or law they were depicting. The question may not have influenced what was taught or how progress was assessed, but rather was used as a means of helping students see the fundamental difference between text based reasoning and visual depictions.

In reading these papers and many more, I have yet to come across anyone who utilized the same format of drawing activity for the students over a broad range of topics in the physical sciences. Biology teachers and Naturalists have used observational notebooks to encourage careful observation and keep records for hundreds of years. Coloring books are popular study aids in the life sciences as we learn anatomy and histology. Using what I can from these authors' work, I tested the idea of using the same format (a sequence of frames like a comic strip) for students to show in two dimensions what we believe is happening on the submicroscopic scale with the goal of significantly improving their performance across multiple topics in a year-long chemistry course.

METHODOLOGY

Drawing primarily from the work of Cooper et al., Stieff and Uttal, and Ainsworth (2017 and 2011), I used an eight-frame template printed horizontally (landscape) on eight and a half by eleven inch paper for students to develop their own two-dimensional models of molecular changes. There were 110 students in my study group.

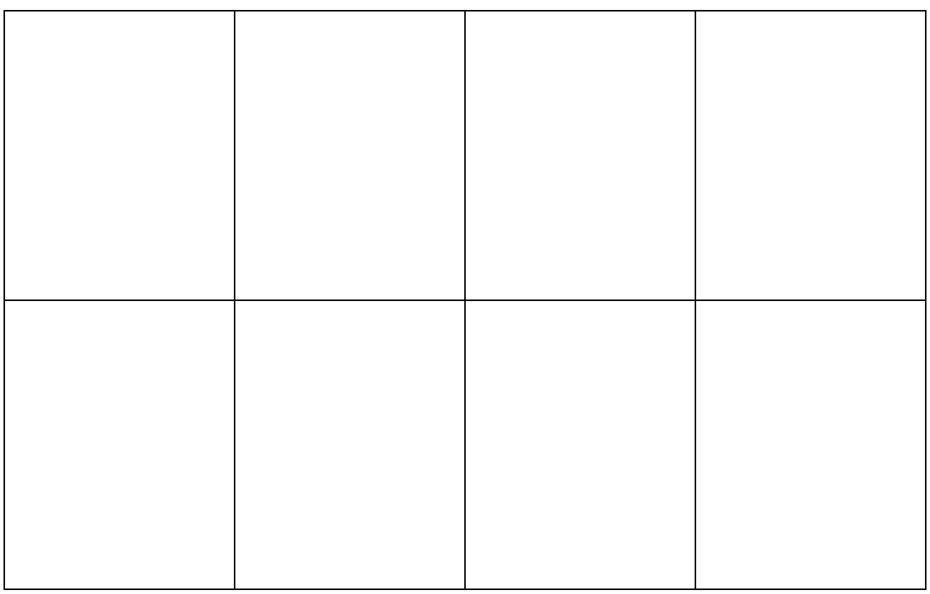

Figure 1. Eight frame template.

The intent was to provide a consistent framework for students to develop their own models, while retaining their previous work in a similar format as the scaffold to develop new depictions of the various processes we were studying. The drawing lessons were done in the intermolecular forces, gas laws, solutions, and thermodynamics units of the course over an academic year. During the intermolecular forces unit, the students constructed drawings of the formation of ionic and covalent bonds. Emphasis was placed on depicting what caused electrons to be shared or transferred among atoms. The gasses unit lesson focused on the relationships between the concepts of temperature, volume, and pressure in the context of kinetic molecular theory. Solutions unit drawings depicted the solvation of ionic and covalently bound solutes in water, emphasizing the interactions of polar solvents with ionic formula units and the sucrose molecule. Thermodynamics drawings were descriptions of phase changes and the quantification of heat energy during the transitions of the physical states.

Performance on summative assessments for those particular units for this year were compared with the two preceding years. Statistical analysis of test scores were made by ANOVA based on the pretest-posttest control group design. While imperfect, our near universal gauge of performance and "success" are the students' grades. Hopefully, these marks from A to F are a fair and accurate representation of not only the student's mastery of the material but also of their performance relative to their peers. Within my department, we use a straight percentage grade scale, with ten percent windows for each traditional grade of A through D, and scores below 60% fail. I compared average student percentages for exams in the topics of molecular bonding, gas behavior, solutions, and thermodynamics. These topics were chosen because the understanding of interaction between particles is emphasized over the calculations, whereas in units such as stoichiometry a student's grades rely more on their skill in mathematics and computation. Our chemistry curriculum and assessment items have been consistent for the past three academic years, with multiple versions of exams using small variations in data provided and scrambled question order, but nearly identical multiple choice questions and free response items.

In the early units, there were multiple lessons involving such drawing in an effort to build skill and confidence. Generally, the curriculum begins with the subatomic and scales upward toward multiple molecule interaction, culminating in acid-base systems in May. During the first unit students were required to include drawings in their homework showing relative size, location, and energetics of protons, neutrons and electrons within atoms. Inclusion of sketches in notes from the text was demonstrated in class, and the process of radioactive decay modeled in a small group activity where students drew a cascade of alpha and beta emissions. The second unit also included instructor modelling of how to sketch processes (ion formation) in their homework. Process specific modelling was not included in the third (periodicity) unit but sketches of the trends in the periodic table were constructed by students.

The formation of covalent and ionic bonds followed the periodicity unit, with multiple lessons on molecular shape, bond polarity and the development of Lewis structures. Thus, the drawing of intermolecular forces and molecular shapes began in late October. The first treatment lesson (compared to the previous two “control” academic years) occurred in this unit. Students were instructed to show the process of ionic and covalent bond formation with emphasis on electron movement and the forces which drive said transfer. Students were encouraged to create a story to provide context (Figure 2).

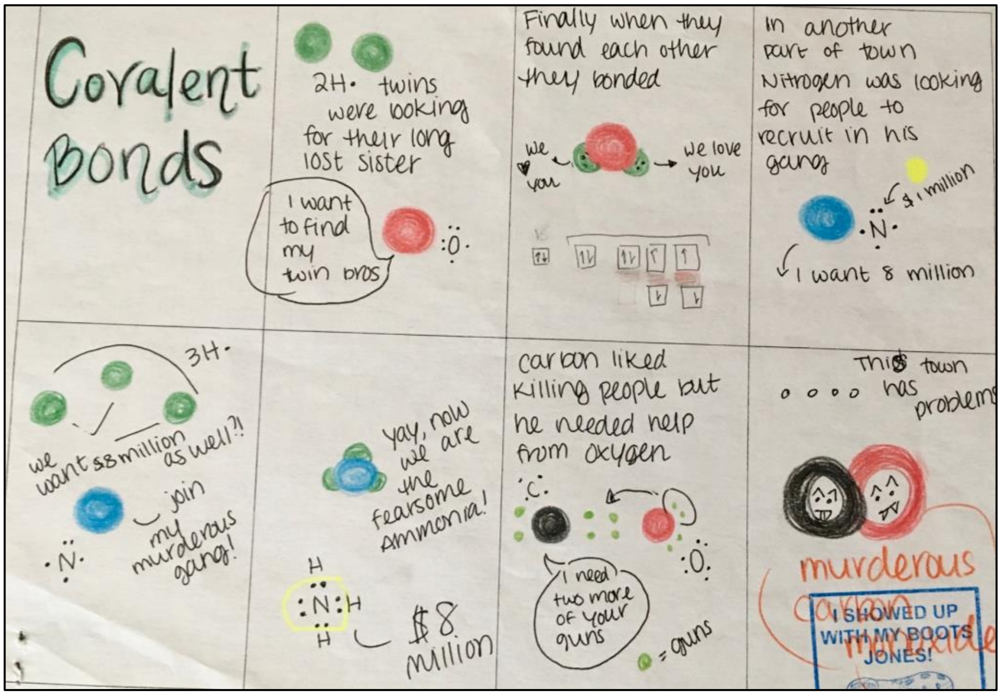

Figure 2. Student images - Bonding.

Immediately following the drawing lesson depicted above, students took an anonymous Likert scale survey (Appendix A – Jones drawing survey) of their expectations from the drawing activity. This was done through the commercial service SurveyMonkey, as it allowed for quick responses and ensured honesty from the students as I would not be able to identify their response. Responses were collected using their smartphones or computers in class. Statistical analysis of survey responses using Chi squared was performed comparing the initial response with subsequent surveys in later unit topics. Survey questions were constructed to measure perceived affect and effect of the activity, and to gauge how often students used sketches in their homework.

The gas laws unit began in February. The same eight frame layout was used to demonstrate altering pressure, temperature and volume on a sample of a single mole of gas. All students began with a representation at standard temperature and pressure (one atmosphere, 0° C) and volume (22.4L), and then depicted gas particles behavior under varying conditions. This activity was followed by the same online survey.

Thermodynamics were studied in March. The drawing lesson asked students to demonstrate the changes of state for a sample compound (nearly all used water) from a solid below the melting point to the gas phase. At this point a small change was implemented. Based on the quality of product and degree of effort invested in the gas unit drawings, this assignment was given credit for completion on time and level of detail. While only a small fraction of their grade, making this an assignment that was “worth points” improved student effort. Work that was done on time and to minimum standards received full credit. Students who needed to make alterations were allowed full credit (10 points) when they made required changes. Surveys were conducted in the same fashion as the other lessons, immediately following the exercise.

Solutions were studied in early April. The drawing exercise was collected and given credit in the same way as the thermodynamics lesson, and the task was to show how the solvation of ionic solutes differ from covalent. Student performance was qualitatively very similar to the efforts in the thermodynamics unit, and was again immediately followed by the survey. As this was the last unit which would contain a drawing exercise, the students were asked some open ended questions where they could anonymously share their views about their enjoyment and perceived effectiveness of the activity compared to our usual mix of “wet” labs, worksheets, and lecture.

Chemistry builds conceptually in a very linear fashion. At the conclusion of the year, students (both randomly selected and a few who indicated positive and negative experiences) were interviewed to determine if the students believed the efforts were time well spent, and asked to draw either the phase change transitions from the thermodynamics unit or molecular shapes from the fall to gauge retention.

Table 1
Data Triangulation Matrix

Focus Question	Data Collection Instruments		
Research SQ. 1: Does adding drawings of molecular processes make a demonstrable impact?	Test score comparison to previous years by ANOVA analysis.	Qualitative analysis of student work	End of year interview demonstrations
Research SQ. 2: do the students believe the drawing activities implemented were worthwhile?	Likert Survey – analysis by chi square	Does this attitude shift? Statistical analysis of survey responses over time	Teacher observation
Research SQ. 3: Can the students apply the concepts they modelled in the drawings to novel situations?	Final interview/student demonstration of retention	Quality assessment of demonstration	

DATA ANALYSIS

The treatment was implemented during the 2018-19 year with a cohort of 110 students in four class sections. Their performance on exams were compared to the two preceding years. In the 2016-17 academic year I taught 153 students in five sections of chemistry and in the 2017-18 year I taught three sections with 91 students.

Generally the average scores between sections for these four units across all three years varied only slightly. The bonding exam covers molecular shapes and how ionic and covalent bonds come to be. Test scores averaged by class over three years were within 1.5%.

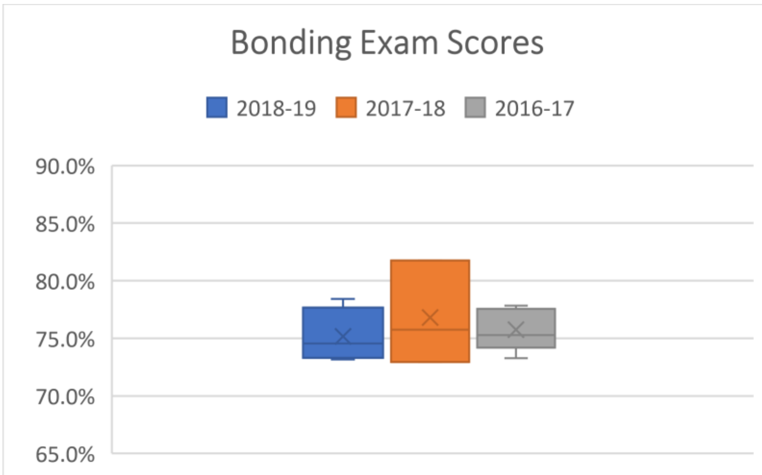

Figure 3. Bonding exam scores over three years.

The Gasses exam covers gas laws and students' understanding of pressure and temperature as kinetic energy on the molecular scale. Test scores (class average) over the three years varied 3.4%.

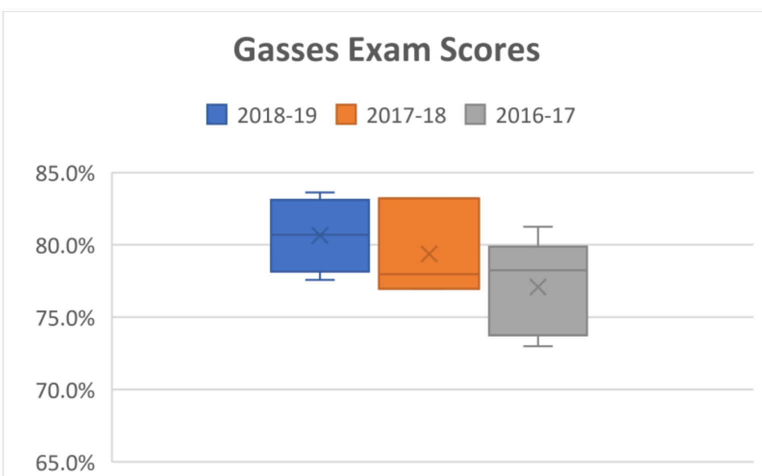

Figure 4. Gas laws exam scores over three years.

The Solutions exam includes intermolecular forces concepts including how polar molecules dissolve other polar and ionic compounds and how it is that non-polar solvents do not. Class averages over the three academic years are within 1.4%.

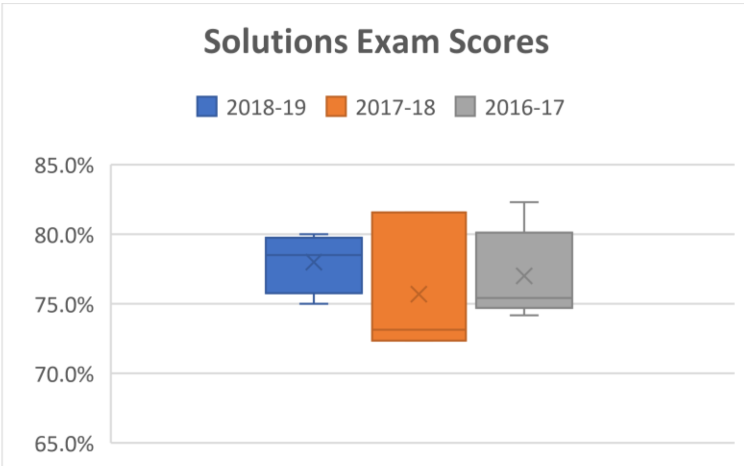

Figure 5. Solutions exam scores over three years.

Thermodynamics had the most variance of class performance with a range of 5.6% over the three years compared. The exam covers phase change and the classification of reactions as those that produce or consume energy to or from the surroundings.

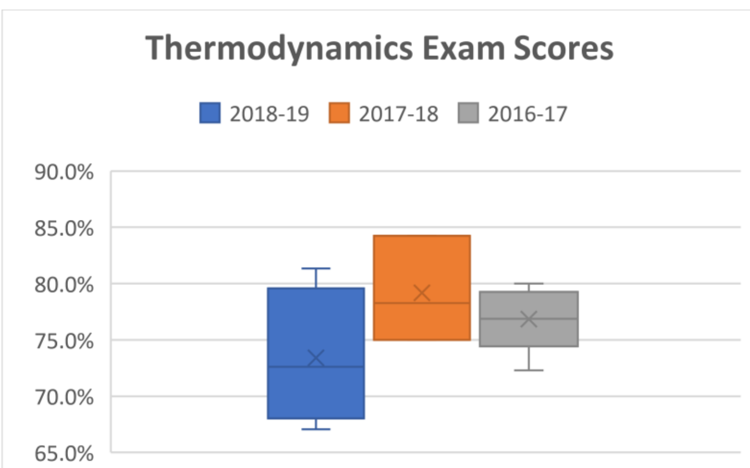

Figure 6. Thermodynamics exam scores over three years.

Statistical analysis with ANOVA show p values demonstrating the probability of the exam results <u>not being positively impacted</u> in the 70% range for two of the exams, and in the 30% range for the other two. With confidence I can attest that the treatment I devised did not improve test performance at the class level.

The second question I endeavored to answer was “Do the students believe the drawing activities implemented were worthwhile?”. This was assessed with anonymous surveys using a Likert scale immediately following the drawing exercises. Statistical analysis for Likert surveys is controversial. I settled on the Chi squared test after reading a paper published in the Journal of graduate medical education by Sullivan and Artino (2013). Considering the goal of determining how students value drawing, the choice was made to compare the last three surveys to the students initial responses. Thus, the null hypothesis was there would be no significant difference between the initial responses in October and the following surveys in November, February, and March. These results, similar to the test scores, show little variation over the treatment period. Students were asked five questions:

1) How often do you put drawings in your notes?
2) Do you believe this exercise was worthwhile?
3) Did you find this exercise enjoyable compared to other activities we do in class?
4) Do you believe the drawing exercises will become more effective as we do more of them?
5) Do you believe the drawing exercises will become more enjoyable as we do more of them?

Question 1 - There was little variation in the inclusion of drawings in the students notes as the year progressed.

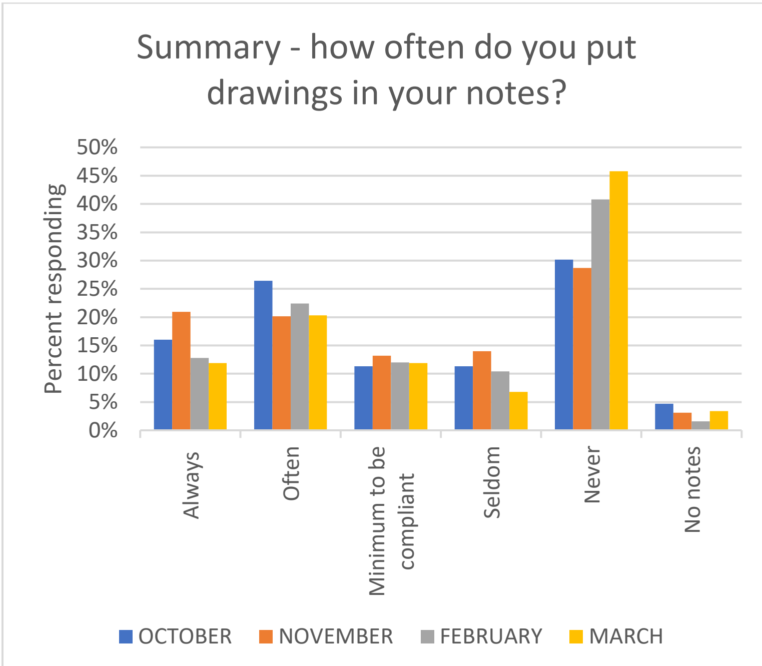

Figure 7. Survey Question - inclusion of drawings in homework.

Approximately half of students included drawings in their notes consistently. As the year progressed there was a marked decrease in drawing in their homework (see February and March values for the number of students who never use drawing in their notes). Ten percent more students chose “never” in February, and fifteen percent more did so in March. Chi squared analysis for this question indicates that the null hypothesis of “no difference between the initial and subsequent surveys” was confirmed with values of 0.999 for the three surveys of November, February and March.

Question 2 - When asked if they enjoyed the activity in comparison to “regular” days in chemistry class, results were slightly more encouraging.

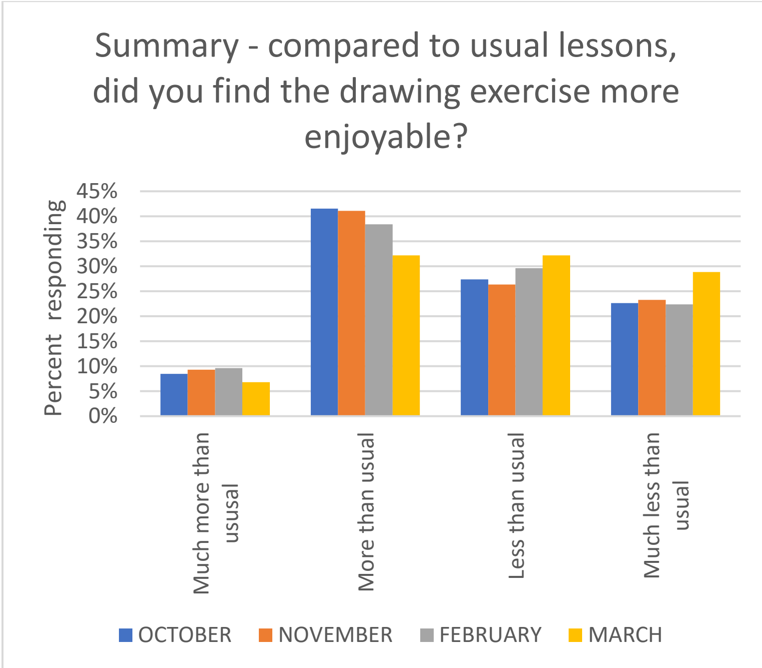

Figure 8. Survey question – Affect at present.

Until March, around half of the students indicated they enjoyed the activity more or much more than the usual lab or problem set lessons. Again, chi squared analysis supports the null hypothesis with two values of 0.999 and one of .997.

Question 3 – Did the students believe the drawing lesson to be effective? This is perhaps the most instructive and encouraging set of responses.

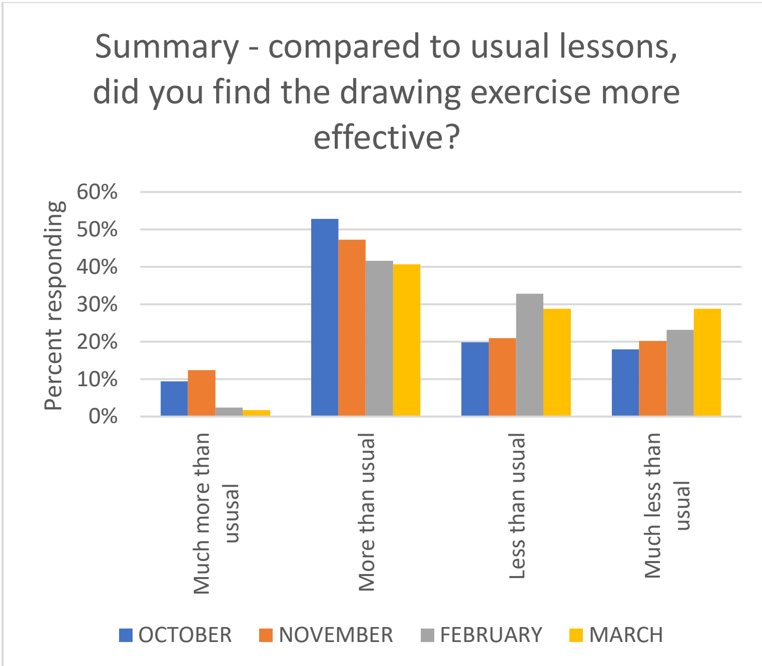

Figure 9. Survey question – Effect at present.

Consistently, the majority of students indicated they found the activity effective. Only 20% found it less effective in the first semester responses, but that partition did climb to around 30% in the second semester. Chi squared values remained consistent at 0.999, 0.981, and 0.977.

Question 4 - Students indicated whether they believed the next drawings would be more effective than the one they just completed. Universally, they did not. With obvious consistency, my students did not have much faith in the next application of this mode of learning to be helpful.

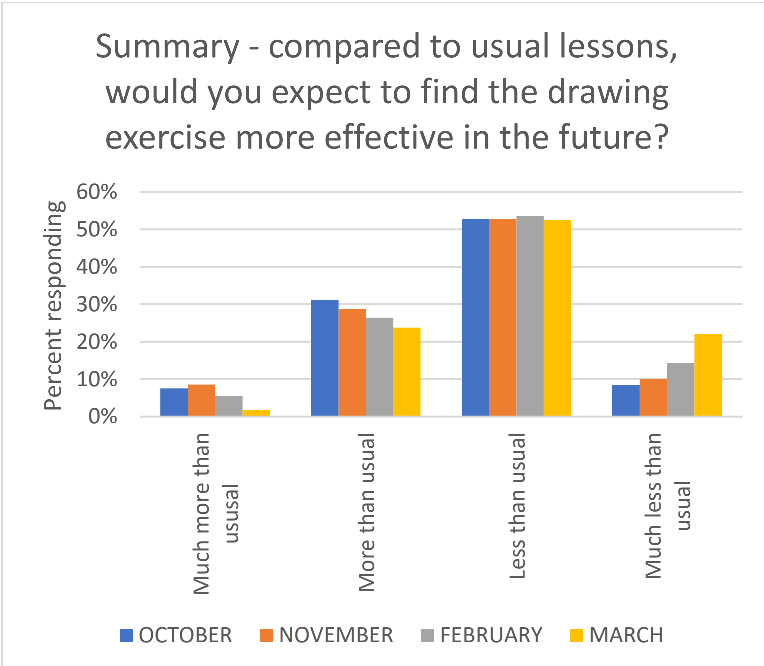

Figure 12. Survey question – Anticipated future effect.

Significantly more than half indicated little confidence that drawing would help them understand new chemistry topics in the future. Chi squared values held at 0.999, 0.997, and 0.996 for the subsequent surveys.

Question 5 - Did the students believe it would be more enjoyable the next time I asked them to draw out a process on the molecular scale? These responses were remarkable in that unlike the others, there was little consistency.

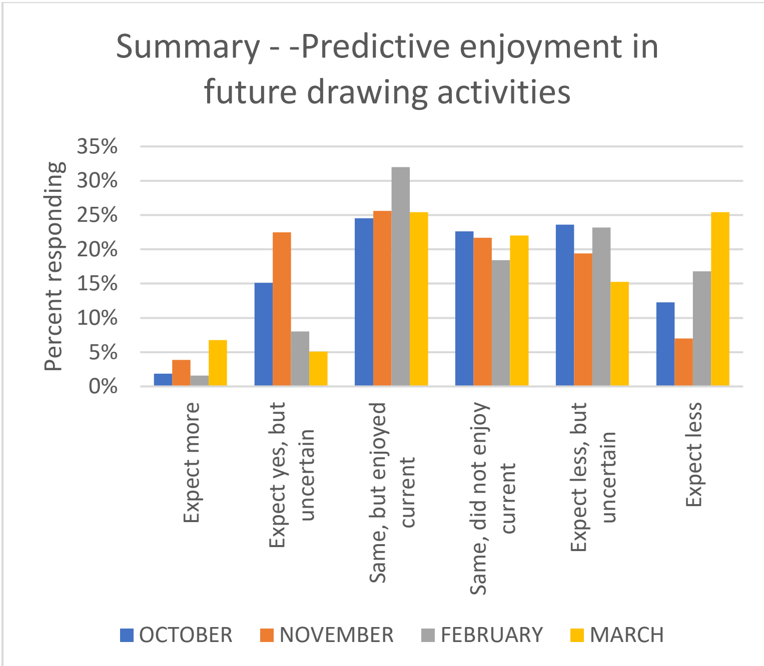

Figure 11. Survey question – anticipated future affect.

While only a small portion expected the next drawing exercise to be more enjoyable than the current lesson, there is a majority of students who believed the next time their experience would be similar. Chi squared test values were 0.999 for the second two surveys, and 0.996 for the last. Fundamentally, there is no statistical basis for arguing a change in any of the survey results from the initial responses.

Last, can the students apply the concepts they modelled in the drawings to novel situations in assessments? This question is the most difficult to answer. Nine student interviews were conducted at the conclusion of the academic year. Ideally, this number would have been larger, but I simply ran out of time to conduct them. The most insightful response was from the last request of the interview, where I asked the students to draw the process of either covalent bond formation or of the energy flow during a phase transition. All of the students succeeded at this task, with only two students leaving out concepts I would consider essential to demonstrating complete understanding. Correlation of the retention of this ability to the inclusion of the drawing exercises in the curriculum is not possible, but it does inspire confidence. Would the students have been able to construct a drawing representing these processes without the practice I required them to do? Answering that would require not providing the practice to some of the students. This was considered, but the choice was made to include all classes in the drawing exercise because I believed it would be beneficial to the students. I could not in good conscience leave out a class to serve as a control. I believe their ability to retain the ability to draw these processes indicates a benefit to the inclusion of the drawing lessons, but this correlation is only grounds for further study. Nine students is too small a cohort to draw conclusions from.

INTERPRETATION AND CONCLUSION

I firmly believe that drawing can play a significant role in learning scientific topics. This work does not support the assertion that having students repetitively use drawing within traditional chemistry units such as gas behavior or bond formation improves exam scores. However, it also does not indicate that other lessons within these topics would have been more effective. As this was a novel approach based on my search of the published literature, I am confident that these efforts can serve as a foundation for my own efforts to continually improve the craft of my teaching.

Overall performance on the exams has been remarkably consistent. Unfortunately, that means the efforts spent by the students and I to improve understanding of actions at the molecular level were not significant. The survey data indicates that only half of my students routinely include drawings in their notes. I had hoped that there would be an increase in this value, but just as with the test score data the responses indicate very little change in how often drawings were included in student notes. In upcoming years, I will explore using the drawing techniques further in both the gas laws and solutions units, but based on this evidence it seems other strategies may be more effective in the intermolecular forces and thermodynamics topics.

Survey data shows a decrease in including drawings in student notes during the Spring months compared to the Fall semester. There may be many causes for this, including “course fatigue”. Nearly 90% of students at Foothill take chemistry to fulfill the physical science graduation requirement. There are only three choices for them that fulfill the University of California standard for a “Laboratory Science” under the university’s area D requirements. One is only available to incoming Freshmen, and during that year most students take biology. For the sophomore year, chemistry is considered by the community to be less demanding than physics. This leads to many students who are simply trying to get through chemistry with the highest ratio of grade to the lowest investment of time and effort. Efforts are underway to provide a new earth and space science course option under NGSS guidelines, but the fact remains that for this cohort chemistry was essentially a required course. The topic is fundamentally difficult, and while our efforts as educators can bolster effort and confidence, that effect lessens as the school year continues toward Spring. Of course, determination of cause is very complex.

I hesitate to make any conclusions about motivation on a large scale. Every student's experience is unique, and I believe needs to be assessed individually.

The slight increase in the student's belief of the treatment's effectiveness over the level of enjoyment is encouraging. Of course, we all want our students to love everything they do in class, but it is called "class work" for a reason. We intend our lessons to push the student's understanding toward a deeper and more complete point with everything we do. In class, I liken some of the activities to strengthening exercises or fundamental skills practice. Musicians rarely love scales, and athletes do not generally revel in sit-ups or squats. We do these things as part of our development toward expertise in whatever endeavor we pursue, yet believing in their value is not always enough to make them enjoyable.

There is a small margin of difference showing that students believed the lessons effective when they were doing them, despite their prediction that it would not be effective the next time. As the second semester began, I made sure to mention this result to the students in each class. I hoped that my revealing to them that the first two surveys revealed that most believed it was more effective than fun would encourage them to give a bit more effort into the drawings when we did them. I buttressed the argument with the apparent increase in exam performance for the gas laws test. I showed the classes the graph indicating an average test score increase of 2-3% over previous years. While I have no evidence that sharing these results resulted in increased motivation, it did prompt asking just that question in the concluding interviews.

The information provided in the exit interviews, while limited, is encouraging. I expected the students to be able to recall some of the factors and forces involved in the processes I asked them to draw. I did not expect seven of nine to represent all of the factors I asked them to include during the lessons. Molecular bonding was covered in October. Phase change in early March. The fact that they remembered so much of that material in late May is supportive of keeping the drawing lessons in the curriculum, but the small group prevents me from assigning much weight to the assertion. The students interviewed were chosen at random, but the circumstance of the interviews has some inherent bias.

Interview opportunities were limited to finals week due to unforeseen changes in the course calendar. Essentially, I lost a week of instructional time to an irregularity in our state testing schedule. The interview results were therefore impacted significantly in two ways. I only interviewed students who had completed their final exams before the allotted time had expired, and they had likely studied for the exam! Obviously, students who were available to interview included the best prepared and those who had calculated that their final exam scores would have little impact on their overall grade in the course. The choice to conduct interviews in this window of time precluded many of my students who had struggled the most. The final course grades for the students interviewed averaged 86%. The final course grade average in the 2018-19 academic year was (and has been over the last three years) 81%.

VALUE

Should drawing be included in our science curricula? I believe the answer is yes. Did this work demonstrate that doing so in the method I implemented improve their understanding? Statistically, I cannot make that claim. However, I will continue to include drawing lessons in my courses. I would make significant changes to the design of this research if it were attempted again. Primarily, I would change my data collection methods. Exam scores may be what the students and their parents care about most, but I should have taken a more holistic view. Form the start, my focus in designing this treatment was to create a concrete data set that would facilitate strong statistical analysis. In pursuing this goal of solid numbers showing how much my students were learning, I missed some real opportunities to glean insight into how my students were learning. For example, tracking free response questions that focused on the conceptual over computational assessment should be included if not emphasized, comparing student performance to a baseline set of questions over the length of the course.

One of our goals across all of science education is to develop student modelling competence. This is a skill that requires constant practice in multiple topics. Drawing in a biology setting and drawing in physics may be a component of very different models, but skill improvement in one may provide significant gains in the other. Drawing is only a piece of modeling, but it is analogous to knife skills or preparing a roux while cooking. We may not always need to draw when developing a model, and not all recipes call for a roux. Yet to be considered competent a chef needs a gamut of skills, just as we should develop a range of skils within our students to provide them with a toolkit suitable to develop models across the scientific disciplines and in technical pursuits from engineering macromolecules to fixing a lawnmower.

In retrospect, I also would have done more student specific work on their own explorations into how they learned best. We tend to emphasize the visual and auditory pathways of information when teaching, even when students are actively in an inquiry format lesson. Especially in chemistry where lab technique is something I dedicate a significant amount of class time to for safety and economic reasons, I am still often demonstrating what I want them to do. Their first exposure to these techniques is by watching. This drove me toward what I believed was the neglected kinesthetic learning pathway. If such a large part of our senses is usually being left out of lesson planning, I hoped I would have demonstrable success by including it.

There are a multitude of reasons why this may be. One may be my idea of emphasizing drawing may have been a deterrent to students who felt they “couldn’t draw”. My telling them that the process of drawing was more important than the degree of artistry they could create did little to assuage these feelings. Drawing may have ultimately become a large part of the academic toolset for some, but my pursuit of “good data” led me away from making the research more student centered. If I were to repeat the project, I would provide a short list of techniques that may improve the student’s academic skills, and allow them to choose one. Then, with the student acting as their own monitor of change in what skills they gained, use that as the hard data I was trying to create. Surveying students on the perceived effectiveness of their choice could be tracked in similar fashion to how I tracked student perceptions on the impact of the drawing activities. In the end, I learned more about how not to do a quantitative study in an education environment than how drawing impacts learning, but what I learned will still help me teach better. I am certain that the desire to continue to improve as a teacher is the most important attribute of becoming a better one.

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APPENDICES

APPENDIX A

JONES DRAWING SURVEY

Appendix A - Jones drawing survey

* 1. How often do you put drawings in your chemistry notes?

- I almost always draw in my notes
- I draw in my notes because Mr. Jones wants me to and it helps
- I draw in my notes only because Mr. Jones wants me to but I don't think it matters
- I draw a couple pictures just to keep Mr. Jones from asking me to. I don't think they help.
- I pretty much don't draw in my notes
- I am too cool to take notes, so this doesn't apply to me!

* 2. Compared to other things we've done in class, do you find the drawing exercise we did today **enjoyable** (was it fun)?

- Not nearly as much as usual
- Less than usual
- More than usual
- Much more than usual

* 3. Compared to other things we've done in class, do you find the drawing exercise we did today **effective** (how much did you learn)?

- Not nearly as much as usual
- Less than usual
- More than usual
- Much more than usual

* 4. Do you think drawing as we did today will be more **effective** when we do it similarly next week?

- I think it will be less helpful
- Maybe it will, but I am not counting on it
- I expect it will be better
- I am certain it will work better

* 5. Do you think drawing as we did today will be more **enjoyable** when we do it similarly next week?

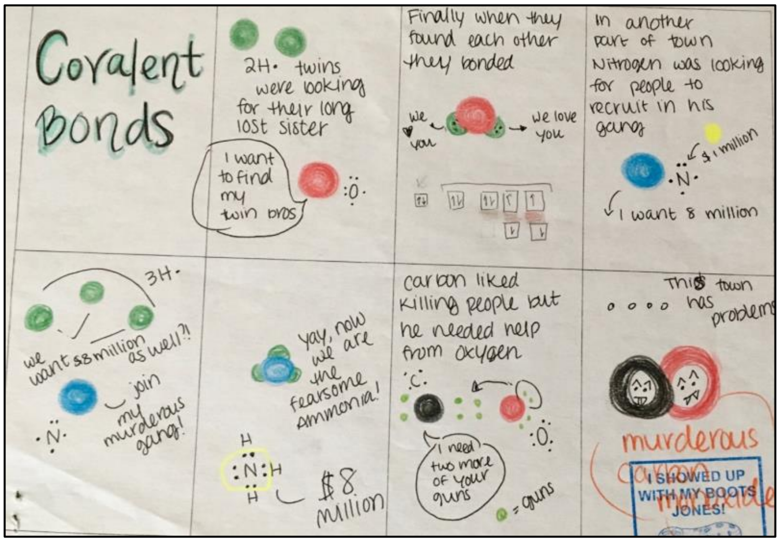
- I think it will be less fun
- Maybe it will, but I am not counting on it
- It'll be the same, and I really didn't enjoy it this time
- It'll be the same, but I liked it this week
- I expect it may be more enjoyable than this week
- I am certain it will be more enjoyable

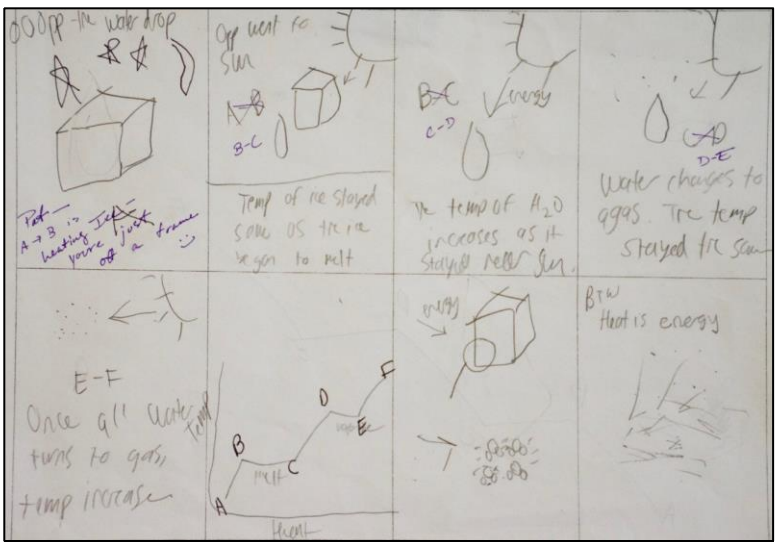
(These are the screens the students saw when taking the survey)

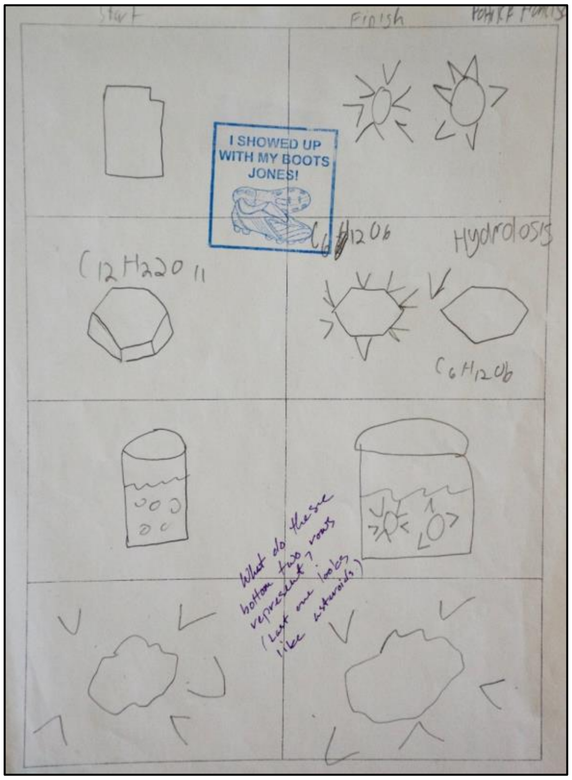
APPENDIX B

STUDENT DRAWINGS

Appendix B Student drawings






Start
Finish
I SHOWED UP WITH MY BOOTS JONES!
C12H22O11
C6H12O6
Hydrolosis
C6H12O6
What do these bottom two rows represent? (Last one looks like asteroids)